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RESEARCH ARTICLE

Influence of alum on cyanobacterial blooms and water quality of earthen fish ponds

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Abstract Eruption of blue-green algal blooms occurs frequently in eutrophic lakes and fish ponds, with associated unpleasant odor and horrid scums. In the present study, we conducted a pre-test experiment in 3 m^3 outdoor concrete ponds to determine the optimum concentration of aluminum sulfate (alum) required for reduction of the cyanobacterial blooms without negative effect on fish growth. As a consequence, 10 mg L^{-1} alum was named as the optimum concentration that was applied in 1000 m^3 earthen fish ponds. Obtained results showed that Secchi disc values significantly increased from 10 to 24 cm after 14 days of alum application. Alum-treated ponds showed a reduction in total phytoplankton counts by 94 and 96 % compared to the corresponding controls after 10 and 14 days, respectively. Abundance of blue-green algae in the treated ponds was decreased by 98 % compared to the corresponding control after 14 days of alum application. Consequently, dissolved oxygen, pH, total phosphorus, orthophosphate, and chlorophyll "*a*" content declined significantly. Our study revealed that using 10 mg L^{-1} of alum is an effective way to control cyanobacterial blooms in eutrophic waters, especially in fish ponds, without negative effect in water quality.

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Introduction

Nile tilapia fingerlings (*Oreochromis niloticus*) are the most widely farmed fish species in Egypt. Good nutrition in fish production systems is essential for economic production of healthy and high-quality fish products. Eutrophication is one of the most serious and widespread water quality problems in the world. When ponds are fertilized with organic and/or inorganic fertilizers in the presence of sunlight, nutrients stimulate the growth of photosynthetic phytoplankton in water. Additionally, water used in fish ponds comes from several sources such as rivers, wells, reservoirs, creeks, or other natural sources. The supplied water contains nutrients, which stimulate the growth of photosynthetic phytoplankton populations, in addition to great amounts of organic and inorganic matter that influence water quality of the pond (Adeoye et al. 2009). The eutrophic water systems usually exhibit extensive algal growth "algal blooms" of nuisance algal species that can prevent light from reaching the pond bottom and reduce the growth of rooted aquatic weeds. Blue-green algal blooms are one of the consequences of eutrophication in freshwaters caused by increasing anthropogenic inputs of nutrients. Such blooms lower water transparency, add poor taste and odor, and eliminate certain fish from the system which may result in an abundance of undesired fish species (Cooke et al. 1977; Lundgren et al. 2013). Prokaryotic blue-green algae (Cyanophyta) such as *Microcystis* and *Anabaena* are frequently observed as blooms in fish ponds. Dodds et al. (2009) and Falconer (2008) concluded that algal blooms may pose serious risks for animal and human health, aquatic ecosystems sustainability, and consequently the economic vitality.

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The dominance of particular algal groups in aquaculture ponds is affected by physical, chemical, and biological factors such as salinity (Burford 1997), light (Levasseur et al. 1984), pond flushing regimes (Tseng et al. 1991), nitrogen to phosphorus ratio (Paerl and Tucker 1995), and availability of nutrients (Boyd 1995). Jhingran (1995) mentioned that several chemical methods, e.g., algaecides and herbicides application, are employed to control harmful algal blooms, but they are too expensive, ineffective, and may cause some residual effects on the aquatic organisms (Anderson 1997). Lembi (2000) reported that using of algaecides to control algal blooms impairs water quality and adds new toxic sediments to the bottom, which interfere bacterial decomposition of sediments and fish growth. In addition, McIntosh and Kevern (1974) recorded negative effect to herbicides on fish growth and reported that they are not environment friendly. Although filter-feeding fish, such as Nile tilapia, are selective algae grazers that can suppress algae through ingestion, they can also enhance algal density indirectly by suppressing herbivorous zooplankton and by increasing nutrients availability (Drenner et al. 1987). On the other hand, aluminum sulfate, commercially known as alum, has been used for long time as a phosphorus inactivant in many studies with different methods of application, for example, dry or dissolved alum, surface or deep application, and with different times of application (James et al. 1991; Babel and Takizawab 2011; Gerde et al. 2014). Results of James et al. (1991) determined that the key reason of algal bloom was internal phosphorus loading, especially during dry weather. They concluded that using of alum for phosphorus inactivation reversed the effects of nutrient loading on ponds and consequently inhibited phytoplankton growth. Moreover, alum is a common water quality amendment used in drinking and wastewater treatment to enhance particulate and phosphorus removal by adsorption and flocculation (Viessman et al. 2008). Barkoh et al. (2013) suggested that alum may be useful for controlling pH in striped bass production ponds where the inorganic fertilization treatment is applied with inhibition of phytoplanktonic growth as a result of phosphate precipitation. Starting around 1980, it became widely accepted that alum was a major factor used for successful treatment in lake restoration and, consequently, success of aquatic organisms and communities to grow in their habitats (Soltero et al. 1981; Malecki-Brown et al. 2010). Alum is acidic in water and can reduce total alkalinity by neutralizing carbonate and bicarbonate compounds, with greater efficiency in reducing pH when applied to water with low initial total alkalinity (Barkoh et al. 2013). A number of studies have been done on application of algaecides and herbicides in fish ponds to control the harmful algal blooms; however, they reported many disadvantages (McIntosh and Kevern 1974; Yin et al. 1989; Jhingran 1995; Anderson 1997; Lembi 2000). The purpose of this paper was to study the effect of different alum concentrations on cyanobacterial blooms and water quality in tilapia earthen fish ponds. In addition, the present study threw some light on the consequent effect of alum application on other phytoplankton and zooplankton abundance.

Materials and methods

Pre-test in outdoor concrete fish ponds

This experiment was designed to determine the optimum concentration of aluminum sulfate, depending mainly on the total phytoplankton count, which could be used in field application. A total of 120 Nile tilapia fingerlings (10 fishes/pond) were grown in 12 outdoor-aerated concrete ponds (3 m^3 water volume capacities each). Four treatments of alum with final alum concentrations of 0, 5, 10, and 15 mg L^{-1} represented to aluminum concentrations of 0, 0.79, 1.58, and 2.37 mg L^{-1}, respectively, were applied in three replicates. Fishes were fed daily on 25 % protein commercial formulated fish feeds at a rate of 3 % of their body weight. Alum crystals were dissolved in distilled water and the solution was filtered through a 0.45-μm pore size filter paper. Each pond was filled with water from Ismailia canal and definite volume (300 L) of aliquots from earthen fish ponds containing algal blooms. Alum solution was thoroughly sprayed on the surface of each pond. Water physico-chemical parameters as well as phytoplankton abundance were estimated after 0 (samples were taken directly after alum application), 5, 10, and 14 days of alum application. In addition, initial average fish body weight was measured in untreated and alum-treated ponds and after 14 days of the experiment to test the effect of alum on fish growth.

Field application in earthen fish ponds

In addition to three untreated earthen ponds (1000 m^3 water volume capacities each with 80–100 cm average water depth), the optimal concentration of alum as determined in the pre-test (10 mg L^{-1}) was applied in other three earthen ponds at Central Laboratory of Aquacultural Research, Abbassa, Egypt (CLAR). Ponds were drained, cleaned, and supplied 2 weeks before fry stocking with freshwater from Ismailia canal throughout El-Wady canal branched from the Nile River. Young-of-year Nile tilapia, averaging 13 g, were stocked at a rate of 1.5 fish m^{-2} during June 2014. All ponds were fertilized by 125 kg of chicken litter/pond/week. Chicken litter, composed of bedding (rice or wheat chaff), manure, feathers, and waste feed, was purchased from the local area. Field measurements including temperature, dissolved oxygen, transparency using Secchi disc, and pH were detected at the head of each pond. In addition, water samples were taken after 0, 3, 5, 7, 10, and 14 days of alum application from five sites in each

pond between 8:00 and 9:00 a.m. at a depth of 30 cm below the water surface and were mixed together in a plastic container according to Boyd (1998) for further studies.

Laboratory analysis

Orthophosphate, total phosphorus, chlorophyll "*a*", nitrate, nitrite, total ammonia, and unionized ammonia were estimated according to the American Public Health Association (APHA 1985). Chlorophyll "*a*" was determined spectrophotometrically according to Vollenweider et al. (1969). Phytoplankton were concentrated by settling of 500 mL of water sample in a volumetric cylinder for about 4 days after being preserved in 0.6 % Lugol's solution (20 g of potassium iodide and 10 g of iodine crystals dissolved in 20 % glacial acetic acid solution). The water was siphoned and 1 mL of sediment was examined microscopically using a Sedgwick-Rafter cell. Algal species were identified according to Prescott (1962, 1978) then sorted in main four algal divisions including Cyanophyta, Chlorophyta, Bacillariophyta, and Euglenophyta. All colonial, filamentous, or unicellular organisms were counted as one unit (cell). In order to determine zooplankton counts, 20 L of water were collected and filtered through a planktonic net with a mesh size of 80 μm. Cells were preserved in 5 % formalin solution and counted using a Sedgwick-Rafter cell. Zooplankton were identified and sorted in four divisions Rotifera, Cladocera, Copepoda, and Ostracoda according to Smith (2001).

Statistical analysis

Results are presented as mean±standard deviation (SD) of three replicates. The statistical analyses were carried out using SPSS version 10. Data obtained were analyzed statistically to determine the degree of significance at $p \leq 0.05$ using Duncan's multiple range test and one-way ANOVA. Pearson's correlation coefficient (r) was used to measure the intensity of the association between different measured parameters in control and alum-treated earthen ponds.

Results

Pre-test in outdoor concrete fish ponds

Application of different concentrations of alum showed insignificant temperature differences (lowest p value=0.0731) at different sampling times (Table 1). Dissolved oxygen and pH significantly decreased by increasing alum concentration

Table 1 Effect of different alum concentrations on water temperature, dissolved oxygen, pH, total ammonia, and unionized ammonia at different sampling times in outdoor concrete fish ponds

Parameters	Sampling time (days)	Alum concentrations			
		Control	5 mg L^{-1}	10 mg L^{-1}	15 mg L^{-1}
Temperature (°C)	0	26.00±0.00^{a}	26.00±0.00^{a}	26.00±0.00^{a}	26.00±0.00^{a}
	5	26.16±0.16^{a}	26.33±0.16^{a}	26.50±0.00^{a}	26.33±0.16^{a}
	10	25.83±0.16^{a}	26.00±0.00^{a}	26.00±0.00^{a}	25.83±0.16^{a}
	14	25.33±0.16^{a}	25.16±0.16^{a}	25.00±0.00^{a}	25.16±0.16^{a}
Dissolved oxygen (mg L^{-1})	0	9.33±0.10^{a}	9.40±0.20^{a}	9.23±0.14^{a}	9.23±0.14^{a}
	5	8.90±0.00^{a}	8.43±0.23^{a}	8.76±0.08^{a}	8.63±0.17^{a}
	10	8.43±0.21^{a}	6.96±0.24^{b}	6.33±0.02^{ab}	6.16±0.08^{c}
	14	7.76±0.31^{a}	6.43±0.14^{b}	5.46±0.17^{c}	5.46±0.37^{c}
pH (cm)	0	9.42±0.02^{a}	9.43±0.03^{a}	9.39±0.09^{a}	9.37±0.04^{a}
	5	9.2±0.11^{a}	9.26±0.12^{a}	9.12±0.11^{a}	8.45±0.03^{b}
	10	9.18±0.09^{a}	8.71±0.02^{b}	8.64±0.07^{b}	8.39±0.22^{b}
	14	8.83±0.05^{a}	8.83±0.09^{a}	8.28±0.24^{b}	7.86±0.08^{b}
Total ammonia (mg L^{-1})	0	0.23±0.03^{a}	0.25±0.06^{a}	0.26±0.05^{a}	0.27±0.05^{a}
	5	0.40±0.06^{a}	0.83±0.15^{ab}	1.13±0.18^{b}	1.27±0.18^{b}
	10	0.80±0.11^{a}	1.53±0.06^{ab}	2.03±0.21^{bc}	2.33±0.37^{c}
	14	1.26±0.17^{a}	1.80±0.11^{a}	2.66±0.33^{b}	2.93±0.06^{b}
Unionized ammonia (mg L^{-1})	0	0.14±0.02^{a}	0.12±0.04^{a}	0.16±0.03^{a}	0.12±0.03^{a}
	5	0.21±0.04^{a}	0.42±0.03^{b}	0.48±0.02^{b}	0.21±0.01^{a}
	10	0.40±0.11^{a}	0.38±0.04^{a}	0.50±0.06^{a}	0.38±0.00^{a}
	14	0.39±0.05^{ab}	0.37±0.12^{a}	0.37±0.09^{ab}	0.13±0.03^{b}

Each value is the mean of three replicates±SD. Values with the same letters at the same row are insignificant at $p \leq 0.05$

after 14 days of alum application, while total ammonia concentration significantly increased (Table 1). Table 2 shows the effect of different alum concentrations on microalgal growth at different sampling times. Generally, total microalgal abundance decreased over time in all studied ponds. Total number of algae decreased in the untreated ponds by 40 % from day 0 to day 14, while treating with 5, 10, and 15 mg L^{-1} alum resulted in a reduction of algal counts by 80, 97, and 99 % after 14 days of alum application. Blue-green algae were the dominant algae in the studied ponds, representing 98 % of the algal composition before the alum application. A highly significant decrease in cyanobacterial abundance was recorded after 14 days of 10 and 15 mg L^{-1} alum application. Using 10 mg L^{-1} alum resulted in a decrease in cyanobacterial counts by 40, 78, and 95 % below the corresponding control after 5, 10, and 14 days, respectively. However, there was no significant difference (lowest p value=0.1033) on cyanobacterial abundance as a result of using 10 and 15 mg L^{-1} alum at all measuring times (Table 2). Fish body weight was averaged from 26 g $fish^{-1}$ at zero time to a final body weight average of 34 g $fish^{-1}$ in all tested ponds after 14 days of alum application. Statistical analysis showed insignificant differences (one-way ANOVA, $p \leq 0.05$) in fish body weight at the same measuring times between all alum-treated ponds and control (Fig. 1).

Field application in earthen fish ponds

Before alum application, ponds were highly eutrophic, as indicated by dissolved oxygen, Secchi disc, orthophosphate, total phosphorus, and chlorophyll "*a*" (Table 3). As a result of alum application, Secchi disc value significantly increased from 10 to 24 cm in 14 days. Depending on Secchi disc values, turbidity of alum-treated ponds was 74 % lower than the corresponding control after 14 days. In addition, dissolved oxygen, pH, orthophosphate, total phosphorus, and chlorophyll "*a*" declined significantly after 14 days of alum application (p values=0.0045, 0.0137, 0.0001, 0.0021, 0.0015, respectively). Alum-treated ponds showed a significant decrease of dissolved oxygen comparing to the corresponding control after 7, 10, and 14 days by 11, 12, and 30 %, respectively. Furthermore, alum-treated ponds showed a significant decrease (p value=0.0331) in pH values compared to the control from day 5 until day 14 of alum application. The lowest

Table 2 Effect of different alum concentrations on phytoplankton abundance (showed as cell number $\times 10^3$ cell mL^{-1}) at different sampling times in outdoor concrete fish ponds

Division	Sampling time (days)	Concentration			
		Control	5 mg L^{-1}	10 mg L^{-1}	15 mg L^{-1}
Cyanophyta	0	137.25 ± 17.34^{a}	140.89 ± 25.38^{a}	148.79 ± 13.71^{a}	143.94 ± 16.96^{a}
	5	131.12 ± 24.22^{a}	121.73 ± 25.65^{a}	78.85 ± 13.30^{b}	74.73 ± 34.01^{b}
	10	94.11 ± 19.15^{a}	47.33 ± 11.53^{b}	20.43 ± 0.84^{c}	20.34 ± 1.42^{c}
	14	82.10 ± 16.12^{a}	28.08 ± 3.15^{b}	3.72 ± 0.65^{c}	1.85 ± 0.46^{c}
Chlorophyta	0	0.12 ± 0.02^{a}	0.13 ± 0.03^{a}	0.13 ± 0.02^{a}	0.13 ± 0.01^{a}
	5	0.06 ± 0.01^{a}	0.05 ± 0.01^{a}	0.04 ± 0.01^{a}	0.05 ± 0.01^{a}
	10	0.06 ± 0.02^{a}	0.04 ± 0.01^{b}	0.04 ± 0.01^{b}	0.03 ± 0.01^{b}
	14	0.04 ± 0.01^{a}	0.06 ± 0.01^{b}	0.04 ± 0.00^{a}	0.05 ± 0.01^{ab}
Bacillariophyta	0	0.14 ± 0.02^{a}	0.14 ± 0.03^{a}	0.13 ± 0.01^{a}	0.12 ± 0.01^{a}
	5	0.08 ± 0.02^{a}	0.11 ± 0.01^{b}	0.09 ± 0.01^{a}	0.09 ± 0.02^{a}
	10	0.06 ± 0.00^{a}	0.09 ± 0.01^{b}	0.06 ± 0.01^{a}	0.05 ± 0.01^{a}
	14	0.05 ± 0.01^{a}	0.08 ± 0.01^{b}	0.05 ± 0.01^{a}	0.06 ± 0.00^{a}
Euglenophyta	0	0.08 ± 0.02^{a}	0.08 ± 0.01^{a}	0.08 ± 0.003^{a}	0.08 ± 0.01^{a}
	5	0.08 ± 0.01^{a}	0.07 ± 0.01^{a}	0.07 ± 0.02^{a}	0.07 ± 0.01^{a}
	10	0.05 ± 0.02^{a}	0.06 ± 0.01^{a}	0.06 ± 0.01^{a}	0.06 ± 0.003^{a}
	14	0.04 ± 0.01^{a}	0.04 ± 0.004^{a}	0.04 ± 0.01^{a}	0.04 ± 0.01^{a}
Total	0	137.59 ± 17.32^{Aa}	141.24 ± 25.41^{Aa}	149.13 ± 13.71^{Aa}	144.27 ± 16.98^{Aa}
	5	131.34 ± 4.96^{Aa}	121.96 ± 18.68^{Ba}	79.05 ± 3.3^{Bb}	74.94 ± 24.01^{Bb}
	10	94.28 ± 9.15^{Ba}	47.52 ± 11.54^{Cb}	20.59 ± 0.85^{Cc}	20.48 ± 1.41^{Cc}
	14	82.23 ± 6.13^{Ca}	28.26 ± 3.15^{Db}	3.85 ± 0.57^{Dc}	2.00 ± 0.65^{Dc}

Each value is the mean of three replicates±SD. Values with the same small letters in the same row and the same capital letters in the same column showed insignificant differences at $p \leq 0.05$

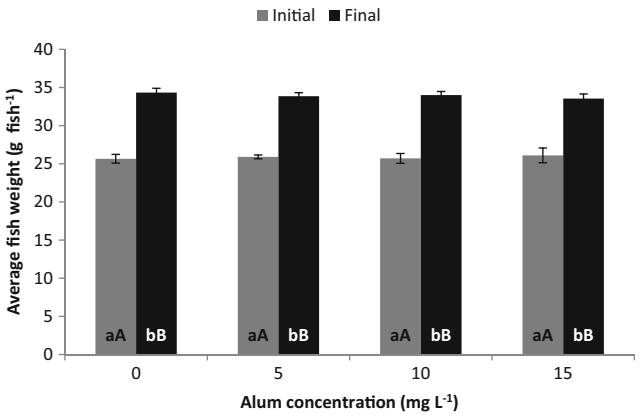

Fig. 1 Effect of different investigated alum concentrations on fish growth in outdoor concrete fish ponds at 0 day and after 14 days of treatment. *Columns with the same letters* show insignificant differences at $p \leq 0.05$

recorded pH value was 8.85 after 14 days of alum treatment (about 4 % lower than the control). A highly significant decrease in orthophosphate concentration was recorded in alum-treated ponds (100 % below the control) after 3 and 5 days (p value=0.0001, for both). The highest concentrations of the total phosphorus were recorded at the start of the experiment by 1.52 and 1.43 mg L^{-1} for control and alum-treated ponds, respectively, while the lowest concentration in alum-treated ponds was 0.23 mg L^{-1} after 7 days of alum application. The highest chlorophyll "*a*" concentration (1118 μg L^{-1}) was recorded in control ponds; meanwhile, the lowest concentration in control ponds (561 μg L^{-1}) after 14 days was about two times higher than the alum-treated ponds (185 μg L^{-1}) at the same sampling time. On the contrary, nitrate concentration showed continuous increase in all studied ponds alongside the study period. The highest nitrate concentration was 0.71 mg L^{-1} in alum-treated ponds after 14 days with 184 % increase with respect to the corresponding control (0.25 mg L^{-1}). Also, a significant increase (lowest p value=0.0021) in total ammonia concentration was recorded in alum-treated ponds comparing to the corresponding control at all sampling times (Table 3). The same trend was observed with unionized ammonia concentrations within different studied ponds. However, nitrite concentration in alum-treated ponds showed a significant decrease by 92 % with respect to the corresponding control after 14 days of alum application.

Table 3 Effect of 10 mg L^{-1} alum treatment on physico-chemical characteristics of water after different application times in earthen fish ponds

Water characteristics	Treatment	Sampling time (days)					
		0	3	5	7	10	14
Temperature (°C)	Control	25.00 ± 0.00^{Aa}	25.00 ± 0.00^{Aa}	25.17 ± 0.17^{Aab}	25.67 ± 0.33^{Abc}	25.83 ± 0.17^{Ac}	26.00 ± 0.00^{Ac}
	Alum	25.00 ± 0.00^{Aa}	25.50 ± 0.00^{Ab}	25.00 ± 0.00^{Aa}	25.30 ± 0.17^{Ab}	26.00 ± 0.00^{Ac}	26.00 ± 0.00^{Ac}
Dissolved oxygen (mg L^{-1})	Control	9.70 ± 0.06^{Aa}	9.40 ± 0.05^{Aa}	8.53 ± 0.25^{Ab}	8.20 ± 0.06^{Aab}	8.17 ± 0.17^{Aab}	7.67 ± 0.33^{Ac}
	Alum	9.67 ± 0.33^{Aa}	9.07 ± 0.07^{Aab}	8.53 ± 0.15^{Ab}	7.23 ± 0.1^{9Bc}	7.17 ± 0.77^{Bc}	5.40 ± 0.23^{Bd}
Secchi disc (cm)	Control	8 ± 1^{Aa}	9 ± 0^{Aab}	9 ± 0^{Aab}	10 ± 0^{Ab}	13 ± 1^{Ac}	14 ± 1^{Ad}
	Alum	10 ± 0^{Aa}	13 ± 1^{Ba}	17 ± 1^{Ba}	22 ± 2^{Bbc}	23 ± 2^{Bbc}	24 ± 5^{Bc}
pH	Control	9.38 ± 0.03^{Aa}	9.33 ± 0.01^{Aa}	9.38 ± 0.01^{Aa}	9.32 ± 0.04^{Aa}	9.29 ± 0.04^{Aab}	9.20 ± 0.03^{Ab}
	Alum	9.34 ± 0.05^{Aa}	9.30 ± 0.03^{Aa}	9.13 ± 0.12^{Bab}	9.00 ± 0.06^{Bbc}	8.97 ± 0.03^{Bbc}	8.85 ± 0.02^{Bc}
Orthophosphate (mg L^{-1})	Control	0.04 ± 0.01^{Aa}	0.04 ± 0.00^{Aa}	0.04 ± 0.02^{Aa}	0.09 ± 0.018^{Aab}	0.12 ± 0.01^{Ab}	0.05 ± 0.01^{Aa}
	Alum	0.12 ± 0.01^{Ba}	0.00 ± 0.00^{Bb}	0.00 ± 0.00^{Bb}	0.06 ± 0.01^{Ac}	0.12 ± 0.01^{Aa}	0.02 ± 0.01^{Ad}
Total phosphorus (mg L^{-1})	Control	1.52 ± 0.16^{Aa}	1.13 ± 0.09^{Ab}	0.85 ± 0.05^{Ac}	0.77 ± 0.01^{Ac}	0.82 ± 0.02^{Ac}	0.41 ± 0.01^{Ad}
	Alum	1.43 ± 0.18^{Aa}	0.74 ± 0.01^{Bb}	0.44 ± 0.03^{Bc}	0.23 ± 0.02^{Bc}	0.33 ± 0.03^{Bc}	0.24 ± 0.03^{Bc}
Chlorophyll "*a*" (μg L^{-1})	Control	1118 ± 153^{Aa}	900 ± 27^{Aab}	739 ± 103^{Abc}	749 ± 22^{Abc}	830 ± 27^{Abc}	561 ± 17^{Ac}
	Alum	1107 ± 160^{Aa}	688 ± 111^{Ab}	446 ± 110^{Abc}	340 ± 53^{Bc}	234 ± 49^{Bc}	185 ± 47^{Bc}
Nitrate (mg L^{-1})	Control	0.10 ± 0.01^{Aa}	0.01 ± 0.00^{Ab}	0.20 ± 0.00^{Ab}	0.25 ± 0.01^{Abc}	0.25 ± 0.10^{Ac}	0.25 ± 0.01^{Ac}
	Alum	0.09 ± 0.02^{Aa}	0.17 ± 0.04^{Bab}	0.23 ± 0.02^{Abc}	0.34 ± 0.02^{Ac}	0.48 ± 0.08^{Bd}	0.71 ± 0.04^{Be}
Nitrite (mg L^{-1})	Control	0.08 ± 0.05^{Aab}	0.01 ± 0.00^{Ab}	0.03 ± 0.01^{Aab}	0.03 ± 0.01^{Aab}	0.02 ± 0.00^{Aab}	0.12 ± 0.04^{Aa}
	Alum	0.12 ± 0.01^{Aa}	0.03 ± 0.01^{Ab}	0.03 ± 0.01^{Ab}	0.02 ± 0.01^{Ab}	0.02 ± 0.00^{Ab}	0.01 ± 0.00^{Bb}
Total ammonia (mg L^{-1})	Control	0.23 ± 0.03^{Aa}	0.30 ± 0.06^{Ab}	0.40 ± 0.12^{Aab}	0.50 ± 0.06^{Aab}	0.66 ± 0.18^{Aac}	0.80 ± 0.12^{Ac}
	Alum	0.20 ± 0.06^{Aa}	0.63 ± 0.09^{Bb}	1.13 ± 0.13^{Bc}	1.40 ± 0.12^{Bcd}	1.73 ± 0.07^{Bd}	1.73 ± 0.18^{Bd}
Unionized ammonia (mg L^{-1})	Control	0.13 ± 0.03^{Aa}	0.17 ± 0.03^{Aa}	0.23 ± 0.07^{Aab}	0.26 ± 0.02^{Aab}	0.36 ± 0.07^{Ab}	0.35 ± 0.03^{Ab}
	Alum	0.10 ± 0.04^{Aa}	0.31 ± 0.04^{Bb}	0.46 ± 0.01^{Bc}	0.49 ± 0.02^{Bcd}	0.59 ± 0.05^{Bd}	0.53 ± 0.02^{Acd}

Each value is the mean of three replicates±SD. Values with the same small letters in the same row and the same capital letters in the same column for each parameter showed insignificant differences at $p \leq 0.05$

The highest phytoplankton counts were observed at the starting day in all studied ponds (Table 4). However, the 10 mg L^{-1}alum-treated ponds showed a reduction in total phytoplankton counts by 94 and 96 % with respect to the corresponding control after 10 and 14 days, respectively (Table 4). Concerning phytoplankton classes, blue-green algae were the most dominant group of phytoplankton standing crop in all studied fish ponds. They recorded maximum counts in control and treated ponds of 235.7×10^3 and 234.5×10^3 cells mL^{-1}, respectively, at the starting sampling day. The abundance of blue-green algae in alum-treated ponds was decreased by 98 % with respect to the corresponding control after 14 days of alum application. Concerning species composition, *Anabaena* showed the highest number (232.4×10^3 cells mL^{-1}) at starting sampling day in control ponds (Table 5), while, the lowest number of *Anabaena* was recorded after 14 days (583 cells mL^{-1}) in alum-treated ponds with 99 % reduction compared to the corresponding control (51, 461 cells mL^{-1}, Tables 5 and 6). *Scenedesmus* represented the highest number (528 cells mL^{-1}) among chlorophytes in alum-treated ponds at the starting day (Table 6), while *Closterium* and *Cosmarium* showed the highest number (135 and 136 cells mL^{-1}, respectively) among chlorophytes in control ponds at the same sampling time (Table 5).

Data recorded in Table 7 showed significant increase in total zooplankton numbers in alum-treated ponds over the corresponding controls up to 10 days after application. After 7 days of alum treatment, Rotifer individuals occupied the first order of abundance (140 organisms L^{-1}), followed by Cladocera individuals (48 organisms L^{-1}), while Copepods and Ostracoda individuals showed less abundance (35 and 15 organisms L^{-1}, respectively). In alum-treated ponds, the highest total zooplankton counts (237 organisms L^{-1}) were observed after 7 days of treatment, then a pronounced decrease during 10th and 14th days (80 and 30 organisms L^{-1}, respectively) was recorded. While control ponds showed an increase in total zooplankton counts up to 72 organisms L^{-1} at 7th day, then followed by a decrease to 45 and 82 organisms L^{-1} during 10th and 14th days, respectively (Table 7).

The relationships between different variables were calculated using the value of the correlation coefficient (r), Tables 8 and 9. Data showed that total phytoplankton counts in control ponds were significantly positively correlated with all water quality parameters except transparency, nitrate, and total phosphorus concentrations which showed negative correlation with phytoplankton counts. While, alum-treated ponds showed the same pattern with positive correlation between total phosphorus concentration and phytoplankton counts. With regard to zooplankton counts, alum-treated ponds exhibited insignificant weak correlation with all biotic and abiotic measured parameters. Significant positive relationships were established between total phytoplankton abundance and chlorophyll "*a*" concentration in control and alum-treated earthen ponds. However, significant negative correlation was recorded between phytoplankton and zooplankton counts in control earthen ponds with insignificant correlation in alum-treated ponds (Tables 8 and 9).

Discussion

Traditional Egyptian aquaculture involves a polyculture of mixed-sex, young-of-year tilapia, common and silver carp, and mullet. Ponds are fertilized with organic and chemical fertilizers, and fish are offered commercial rations. Studies of Green et al. (1995) on management of fish earthen ponds at the Central Laboratory for Aquacultural Research, Abbassa, Egypt, using five management systems reported that the

Table 4 Total phytoplankton count ($\times10^3$ cell mL^{-1}) in 10 mg L^{-1} alum-treated and non-treated earthen fish ponds after different application times

Algae class	Treatment	Sampling time (day)					
		0	3	5	7	10	14
Cyanophyta	Control	235.7 ± 68.1^{Aa}	168.7 ± 16.4^{Ab}	134.9 ± 8.2^{Abc}	111.0 ± 11.1^{Ac}	128.4 ± 7.9^{Ac}	51.8 ± 6.0^{Ad}
	Alum	234.5 ± 30.1^{Aa}	123.9 ± 7.1^{Bb}	29.6 ± 7.5^{Bc}	12.1 ± 2.2^{Bc}	6.8 ± 1.2^{Bc}	1.2 ± 0.1^{Bc}
Chlorophyta	Control	0.65 ± 0.08^{Aa}	0.48 ± 0.04^{Aab}	0.31 ± 0.04^{Abc}	0.31 ± 0.06^{Abc}	0.29 ± 0.03^{Abc}	0.27 ± 0.08^{Ac}
	Alum	0.98 ± 0.07^{Aa}	0.69 ± 0.04^{Ba}	0.71 ± 0.16^{Ba}	1.02 ± 0.11^{Ba}	1.08 ± 0.35^{Ba}	0.50 ± 0.07^{Ba}
Bacillariophyta	Control	0.16 ± 0.03^{Aa}	0.09 ± 0.02^{Abc}	0.09 ± 0.01^{Abc}	0.12 ± 0.01^{Aab}	0.06 ± 0.01^{Abc}	0.05 ± 0.01^{Ac}
	Alum	0.26 ± 0.01^{Ba}	0.13 ± 0.02^{Aa}	0.20 ± 0.02^{Ba}	0.19 ± 0.04^{Aa}	0.29 ± 0.05^{Ba}	0.25 ± 0.11^{Ba}
Euglenophyta	Control	0.12 ± 0.02^{Aa}	0.09 ± 0.02^{Aab}	0.09 ± 0.02^{Aab}	0.07 ± 0.02^{Aab}	0.10 ± 0.00^{Aa}	0.03 ± 0.007^{Ab}
	Alum	0.13 ± 0.03^{Aab}	0.11 ± 0.03^{Aab}	0.08 ± 0.02^{Ab}	0.19 ± 0.03^{Ba}	0.08 ± 0.01^{Bb}	0.11 ± 0.03^{Bab}
Total	Control	236.63 ± 68.20^{Aa}	169.36 ± 16.40^{Ab}	135.39 ± 8.20^{Abc}	111.50 ± 11.10^{Ac}	128.85 ± 7.90^{Ac}	52.15 ± 6.10^{Ad}
	Alum	235.87 ± 30.10^{Aa}	124.83 ± 7.20^{Bb}	30.59 ± 7.70^{Bc}	13.50 ± 2.30^{Bc}	8.25 ± 0.90^{Bc}	2.06 ± 0.20^{Bc}

Each value is the mean of three replicates±SD. Values with the same small letters in the same row and the same capital letters in the same column for each group showed insignificant differences at $p\leq0.05$

Table 5 Variation in phytoplankton counts (cell mL^{-1}) in non-treated earthen fish ponds

Phytoplankton	Sampling time (days)					
	0	3	5	7	10	14
Cyanophyta						
Anabaena	232,412	164,658	133,201	110,203	127,984	51,461
Anabaenopsis	802	187	150	102	84	55
Chroococcus	530	33	33	22	11	22
Gloeocapsa	79	66	55	33	22	22
Merismopedia	51	11	11	11	nd	nd
Microcystis	1842	3790	1494	684	325	212
Chlorophyta						
Asterococcus	102	36	25	22	33	nd
Chlorella	33	62	47	66	11	3
Closterium	135	73	40	29	47	33
Clostridium	11	22	11	11	33	22
Cosmarium	136	51	22	11	22	11
Monoraphidium	62	55	14	62	55	22
Pediastrum	11	25	22	11	31	22
Scenedesmus	77	108	88	55	69	65
Staurastrum	51	22	11	nd	nd	51
Tetraedron	22	3	22	11	11	22
Tribonema	11	22	11	33	11	22
Bacillariophyta						
Cyclotella	73	34	22	14	11	3
Navicula	22	14	25	25	33	14
Nitzschia	68	44	44	77	18	36
Euglenophyta						
Euglena	77	47	55	33	47	25
Phacus	44	44	36	35	55	11

Each value is the mean of three replicates

nd not detected

traditional Egyptian and *fertilization then feed* treatments exhibited insignificant differences in total tilapia yield, indicating that the addition of commercial ration of fertilizers was not necessary during the first 2 months of culture at CLAR. In addition, Green et al. (1995) reported that fertilizer applications beyond day 60 in the *traditional Egyptian* treatment did not appear to affect tilapia yield significantly when compared to the *fertilization then feed* treatment. Thus, they concluded that fertilizer application beyond day 60 in the *traditional Egyptian* treatment was not necessary. Depending on their results, the present study was conducted using *traditional Egyptian* treatment without application of post-fertilization. Eutrophication of water results in dense algal blooms causing changes in water quality which are deleterious to fish populations or may be directly toxic to other aquatic organisms (Shilo 1967; Bernardi and Giussani 1990; Sivonen and Jones 1999; Lundgren et al. 2013). Lu et al. (2006) stated that nutrient reduction from internal and external loading is the ultimate way to control eutrophication and, consequently, blue-green algal blooms. However, this approach does not always work, especially in highly eutrophic lakes or ponds where algal growth no longer depends on nutrient concentrations (Sas 1989; Seip 1994) and reduction of nutrients to very low levels is often difficult (Lu et al. 2006). Alum treatment might be one of cost-effective methods used to control harmful algal blooms. The pre-test experiment in outdoor concrete fish ponds indicated a significant decrease in total count of phytoplankton using 5 mg L^{-1} of alum which was more pronounced using 10 mg L^{-1} (Table 2). There was no significant difference between the total count of phytoplankton as a result of applying 10 and 15 mg L^{-1} of alum. In addition, there were no significant differences in fish average body weight in control ponds and that treated with different concentrations of alum for 14 days (Fig. 1). Although 10 and 15 mg L^{-1} alum were recorded as effective concentrations; 10 mg L^{-1} was selected as the optimum concentration to be used in the field experiment in order to reduce the cost of alum application.

Table 6 Variation in phytoplankton counts (cell mL^{-1}) in 10 mg L^{-1} alum-treated earthen fish ponds

Phytoplankton	Sampling time (days)					
	0	3	5	7	10	14
Cyanophyta						
Anabaena	228,461	123,497	28,956	12,532	6365	583
Anabaenopsis	279	230	94	310	418	33
Gloeocapsa	73	43	nd	nd	148	11
Merismopedia	73	39	39	59	59	nd
Microcystis	4607	124	554	197	55	246
Chlorophyta						
Asterococcus	121	73	47	72	182	72
Chlorella	33	101	102	132	77	39
Cosmarium	33	22	11	33	nd	nd
Closterium	92	66	110	187	180	64
Mallomonas	nd	nd	nd	51	42	11
Monoraphidium	nd	nd	51	39	33	59
Scenedesmus	528	185	209	178	223	94
Staurastrum	63	137	118	199	196	132
Tetradesmus	22	91	22	22	33	11
Tetraedron	22	11	33	51	73	39
Tribonema	66	11	11	59	39	nd
Bacillariophyta						
Cyclotella	22	11	11	11	51	39
Navicula	179	73	158	105	142	190
Nitzschia	61	44	33	70	97	22
Euglenophyta						
Euglena	66	92	62	166	66	103
Phacus	66	22	22	22	11	11

Each value is the mean of three replicates

nd not detected

Lu et al. (2006) concluded that nutrients budget in natural lakes or ponds are affected by multiple factors including external loading and internal cycling. As a result of application of 10 mg L^{-1} alum in earthen fish ponds (Table 3), all water quality parameters were within the acceptable ranges for fish growth according to Boyd (1979). Our study showed increases in Secchi disc and decrease in nutrient concentrations in alum-treated ponds because of the associated reduction of algal biomass and other particulate in the water column by alum. Obtained results showed a positive correlation between phytoplankton growth and dissolved oxygen concentration (Tables 8 and 9), which is in agreement with the finding of Boyd (1998). The recorded decrease of oxygen concentration during treatment with alum compared with control is attributed to the decrease in phytoplankton growth. As dissolved oxygen saturation point is 8.5 mg L^{-1} at 25 °C, the increase in dissolved oxygen recorded in Table 3 confirms that the dissolved oxygen was affected not only by algal photosynthesis but also by aquatic respiration, oxidative decomposition of settled organic compounds such as nutrients, fish, and animal wastes (Kunlasak et al. 2013). Koohestanian et al. (2008) stated that 85–98 % reduction of water turbidity can be achieved using the optimum coagulant dosage (8 mg L^{-1} ferric chloride and 10 mg L^{-1} alum) in the optimum pH range (9.2 for ferric chloride and 8.5 for alum) which is in agreement to the present results. Boyd (1998) concluded that acid and alkaline death points for fish are approximately at pH values of 4 and 11, respectively. The recorded pH in the present study (Table 3) lies in alkaline range (8.9–9.3) which is suitable for the growth of aquatic organisms. Brunson et al. (1994) mentioned that in waters that have a low or moderate buffering capacity, dense blooms cause pH to reach values of 10 or above which depress fish growth and health. On the other hand, alum is known to lower the pH value (Miskimmin et al. 1995; Yee et al. 2000;

Table 7 Zooplankton counts (organism L^{-1}) in 10 mg L^{-1} alum-treated and non-treated earthen fish ponds after different application times

Zooplankton division	Treatment	Sampling time (days)					
		0	3	5	7	10	14
Cladocera	Control	10.0 ± 2.8^{Aa}	8.3 ± 1.6^{Aa}	11.6 ± 3.3^{Aa}	11.6 ± 1.6^{Aa}	3.3 ± 1.6^{Aa}	10.0 ± 2.8^{Aa}
	Alum	5.0 ± 0.0^{Aa}	20.0 ± 7.6^{Ab}	86.6 ± 11.6^{Bc}	48.3 ± 4.4^{Bd}	20.0 ± 4.8^{Bb}	6.6 ± 1.6^{Aa}
Copepoda	Control	11.6 ± 7.2^{Aa}	26.6 ± 4.4^{Aa}	20.0 ± 10.4^{Aa}	20.0 ± 7.6^{Aa}	16.6 ± 6.0^{Aa}	25.0 ± 5.7^{Aa}
	Alum	25.0 ± 7.63^{Aa}	105.0 ± 15.2^{Bb}	60.0 ± 7.3^{Bc}	35.0 ± 2.8^{Aa}	11.6 ± 1.6^{Aad}	5.0 ± 0.0^{Bd}
Rotifera	Control	6.6 ± 1.6^{Aa}	11.6 ± 1.6^{Aa}	21.6 ± 7.2^{Aa}	23.3 ± 11.7^{Aa}	11.6 ± 3.3^{Aa}	23.3 ± 1.6^{Aa}
	Alum	10.0 ± 2.8^{Aa}	23.3 ± 3.3^{Bab}	41.6 ± 1.6^{Bb}	140.0 ± 18.0^{Bc}	43.3 ± 6.0^{Bb}	18.3 ± 6.3^{Aa}
Ostracoda	Control	6.6 ± 4.4^{Aa}	8.3 ± 1.6^{Aa}	15.0 ± 2.8^{Aab}	16.6 ± 1.6^{Aab}	13.3 ± 4.4^{Aab}	23.3 ± 3.3^{Ab}
	Alum	5.0 ± 0.0^{Aa}	28.3 ± 4.6^{Bb}	41.6 ± 3.6^{Bc}	13.3 ± 4.4^{Ad}	5.0 ± 0.0^{Ba}	0.0 ± 0.0^{Be}
Total	Control	34.8 ± 7.6^{Aa}	54.8 ± 5.0^{Abc}	68.2 ± 7.3^{Abc}	71.5 ± 12.0^{Abd}	44.8 ± 10.4^{Aac}	81.6 ± 4.4^{Ad}
	Alum	45.0 ± 5.7^{Aa}	176.6 ± 6.6^{Bb}	229.8 ± 20.8^{Bc}	236.6 ± 21.6^{Bc}	79.9 ± 8.6^{Bd}	29.9 ± 2.8^{Ba}

Each value is the mean of three replicates±SD. Values with the same small letters in the same row and the same capital letters in the same column for each group showed insignificant differences at $p\leq0.05$

Table 8 Pearson's correlation coefficient (r) between different measured parameters in control earthen fish ponds

	DO	PH	SD	NH_3	NO_3	TP	Chl. *a*	Phytopl.	Zoopl.
DO	1								
pH	0.747*	1							
SD	−0.852*	−0.911*	1						
NH_3	−0.937**	-0.783^{ns}	0.936**	1					
NO_3	−0.886*	-0.471^{ns}	0.686^{ns}	0.783*	1				
TP	0.965**	0.816*	−0.848*	−0.861*	−0.794*	1			
Chl. *a*	-0.378^{ns}	-0.197^{ns}	0.186^{ns}	0.407*	0.106^{ns}	-0.278^{ns}	1		
Phytopl.	0.947**	0.810*	−0.798*	0.844*	−0.708*	−0.974**	0.470*	1	
Zoopl.	-0.728^{ns}	-0.589^{ns}	0.454^{ns}	0.485*	0.485^{ns}	−0.832*	0.367^{ns}	−0.877*	1

*Significant at $p \leq 0.05$, **significant at $p \leq 0.01$, *ns* not significant

Barkoh et al. 2013). Therefore, we suggest that the present system was auto-buffered which resulted in no critical reduction in the pH. The recorded decrease in total phosphorus and orthophosphate (Table 3) may be explained by their combination with Al^{3+} under alkaline conditions (pH 8.8–9.9) forming a complex which settles down into the bottom of the ponds (Tucker and D'Abramo 2008) or might be a result of alum which forms large, visible, non-toxic precipitates of aluminum hydroxide that settles through the water column to the sediments and controls sediment phosphorus release rates (Holz and Hoagland 1999). There is a direct relationship between nutrients and phytoplankton density. Nitrogen is one of essential nutrients for phytoplankton growth. Syrett (1981) reported that nitrate and ammonia stimulate the growth of almost all chlorophyll-containing algae. However, in the present study, the recorded increase of nitrate and ammonia concentrations in alum-treated ponds (Table 3) with synchronous decrease in phytoplankton counts (Table 4) might be attributed to accumulation of nitrate and ammonia in the pond as a result of death of algae, which consume nitrate and ammonia for their nutrition (Boyd 1998; Joy et al. 1990). Although ammonia concentrations in alum-treated ponds were increased with respect to the corresponding control (Table 3), the recorded values of ammonia were still in the safe range recommended by the European Inland Fisheries Advisory Commission (EIFAC 1973).

The highest counts of cyanobacteria were observed at the starting day of experiment in all studied ponds (Table 4). The recorded decrease in cyanobacterial abundance alongside 14 days, even in untreated ponds, may be explained by the findings of Lu et al. (2006) who concluded that tilapia is among the very few fish species which are capable of digesting blue-green algae. Tilapia secretes gastric acid at a pH as low as 2.5 to 1.0 during digestion which enhances the digestion of blue-green algae (Morrison and Wright 1999). Another reason for decreasing the cyanobacterial abundance in untreated ponds might be the natural settlement and decomposition of phytoplankton cells because of the synchronous decrease of dissolved oxygen. However, obtained results showed that alum application significantly reduced cyanobacterial growth with respect to the corresponding controls (Table 4). This finding may be explained by the statement of Welch and Schrieve (1994) and Tucker and D'Abramo (2008) who mentioned that alum reacts with water forming aluminum hydroxide. Phosphorus and other suspended particles including phytoplankton react with aluminum hydroxide

Table 9 Pearson's correlation coefficient (r) between different measured parameters in 10 mg L^{-1} alum-treated earthen ponds

	DO	PH	SD	HH_3	NO_3	TP	Chl. *a*	Phytopl.	Zoopl.
DO	1								
pH	0.985**	1							
SD	−0.967**	−0.969**	1						
NH_3	0.922**	0.954**	−0.941**	1					
NO_3	−0.981**	−0.979**	0.983*	−0.96**	1				
TP	0.885*	0.740^{ns}	-0.846^{*}	0.560^{ns}	-0.732^{ns}	1			
Chl. *a*	0.871*	0.825*	−0.900*	0.700^{ns}	−0.838*	0.977**	1		
Phytopl.	0.804*	0.761*	−0.838*	0.608*	−0.754*	0.989**	0.987**	1	
Zoopl.	0.257^{ns}	0.316^{ns}	-0.286^{ns}	0.568^{ns}	-0.392^{ns}	-0.233^{ns}	-0.127^{ns}	-0.137^{ns}	1

*Significant at $p \leq 0.05$, **significant at $p \leq 0.01$, *ns* not significant

forming a relatively insoluble mass "floc." The formed "floc" settles down due to many factors including a reduction of electrical charges. Holz and Hoagland (1999) concluded that alum was extremely effective in reducing phytoplankton biomass and shifting phytoplankton community composition from cyanophytes dominance toward bacillarophytes and chlorophytes, increasing usable fish habitat. Although alum treatment enhanced the clarity of water by 140 % after 14 days of application (Table 3), the water remained turbid with a mean Secchi disc of 24 cm. This finding might be due to other different turbidity sources such as suspended clay particles and/or mechanical activities at the ponds. In conversely, our results confirmed that cyanophytes dominated over chlorophytes and other groups of phytoplankton at all sampling times which might be attributed, in addition to the environmental factors, to the difference predation pressure on zooplankton due to differences in shelter. Concerning species composition, *Anabaena* was the dominant species among all detected algae (Tables 5 and 6), which may be attributed to its ability to inhibit the growth of other algae by secretion of toxic metabolites. Schagerl et al. (2001) and Volk (2005) found that *Anabaena* produces an allelochemical which causes growth inhibition for other cyanobacteria. On the other hand, the present study revealed that some species, like *Gloeocapsa*, *Mallomonas*, and *Staurastrum*, disappeared at certain periods and reappeared later (Table 6) which is in agreement with findings of El-Ayouty et al. (1999) and Ahmad et al. (2001) in their studies on Abbassa fish ponds. Preston et al. (1980) stated that summer populations of *Microcystis* in the water column originate from over-wintering sediment colonies which might be the reason of such sudden disappearance and reappearance of some algal species, or it might be attributed to the selective predation of zooplankton.

Zooplankton plays an important role in the biological productivity of aquatic ecosystems (Mason 2001). Many environmental factors are considered important in setting zooplankton distribution patterns, such as turbulence, light intensity, temperature, dissolved oxygen concentration, and chlorophyll "*a*" content (KiØrboe and Saiz 1995). In the present study, the lowest number of zooplankton (Table 7) was recorded in the case of blooming which might be due to some allelochemicals released by blue-green algae which not inhibit only other phytoplanktonic organisms but also zooplankton, e.g., inhibiting nutrition and reproduction among some rotifers (Uhlman 1961) and certain cladocerans (Arnold 1971). In addition, Sevrin-Reyssac and Pletikosic (1990) reported that blue-green algae are phytoplankton of poor food value to zooplankton, their large size makes them inaccessible to the filter feeding entomostraca. The present results showed that alum application led to an increase of total zooplankton number over the control up to 10 days of alum application (Table 7) which may be attributed to the decrease of *Anabaena* sp. and its secondary metabolites effects. This finding is in agreement with Yang et al. (2005) who recorded large changes in zooplankton community structure coincided with markedly changes in the concentration of chlorophyll "*a*" in Lake Donghu, China. The changes in zooplankton counts and structures are strongly affected by environmental conditions, phytoplankton occurrence and/or the impact of cultured fish (Masson et al. 2001). Moreover, the insignificant correlation between total zooplankton counts and all measured parameters in alum-treated earthen ponds might be attributed to the significant reduction of phytoplankton.

Conclusion

Our results revealed that 10 mg L^{-1} alum effectively reduced blue-green algal biomass and decreased the water turbidity of tilapia earthen ponds without any negative effect on fish growth. In addition, using of 10 mg L^{-1} of alum showed no negative effect on water quality since the recorded values of different physico-chemical water parameters were in the safe range recommended by international standards. However, alum application in fish ponds without disadvantages eventually resulted in a reduction of zooplankton and other living aquatic organisms, which might affect the natural community of water. Future research will be needed to gain more explanation for the relationship between nutrient dynamics, algal biomass, and stocking density of herbivorous fish in alum-treated earthen fish ponds. In addition, further research is needed to study the long-term effects of alum application in fish ponds on water quality and fishes.

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